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Title:

Measurement of the Equivalent Fundamental-Mode Source Strength

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Measurement of the Equivalent Fundamental-Mode Source Strength

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Abstract

The steady-state multiplication, M, of a subcritical system that is in equilibrium with an external/intrinsic source is defined as the total *neutron-production* rate divided by the external/intrinsic neutron source rate, S. The total neutron-production rate, in this context, is the sum of the fission-production rate plus the source rate. Because the system is in equilibrium, the total neutron-production rate is identically equal to the loss rate from the system due to absorption plus leakage. If the source S is distributed identically to the fission source distribution (i.e., angle, energy, and space), then M will be related to the effective multiplication factor of the system, k_{eff}, as

$$M = \frac{1}{1-k_{eff}} \quad . \tag{1}$$

The quantity $1/(1 - k_{eff})$ is defined as the fundamental-mode multiplication, M_o, since it represents the multiplication that would occur if the source S were distributed as the fundamental-mode fission source. However, in nature, external/intrinsic sources usually occur as uniformly-distributed sources, such as intrinsic sources produced by spontaneous fissioning of one or more of the isotopes contained in the fuel, or as point sources that have been placed in or near the assembly, such as an external start-up source. A uniformly-distributed intrinsic source or an external point source placed in or near an assembly will produce a system multiplication, M, that can differ significantly from the fundamental-mode multiplication, M_o.

Because it is customary in reactor physics to express most quantities in terms of the effective multiplication factor, k_{eff}, it is necessary to modify Eq. (1) by including a factor, g^*, that allows us to express the actual multiplication produced by an arbitrary source distribution in terms of the fundamental-mode multiplication. That is,

$$M = g^* M_o = \frac{g^*}{1 - k_{eff}} \quad . \tag{2}$$

The factor, g^*, is equal to the average importance of a source neutron divided by the average importance of a fission neutron:

$$g^* = \frac{\overline{\Psi}_s}{\overline{\Psi}_f} \quad , \tag{3}$$

which can be evaluated from the following expression derived from transport theory.[1]

$$g^* = \frac{\int \Psi \chi_s s \; d\Omega dV dE}{\int \chi_s s \; d\Omega dV dE} \times \frac{\int \chi_f \bar{\nu}_t \Sigma'_f \Phi' d\Omega' dE' \; d\Omega dV dE}{\int \Psi \chi_f \bar{\nu}_t \Sigma'_f \Phi' d\Omega' dE' \; d\Omega dV dE} \quad , \tag{4}$$

where

$\Phi = \Phi(\boldsymbol{r}, \Omega, E)$ = angular flux (forward solution),
$\Psi = \Psi(\boldsymbol{r}, \Omega, E)$ = angular flux (adjoint solution),
$\Sigma'_f = \Sigma'_f(\boldsymbol{r}; \Omega', E' \rightarrow \Omega, E)$ = macroscopic fission cross section,
$\bar{\nu}_t = \bar{\nu}_t(\boldsymbol{r}, E')$ = the average of the total number of neutrons released per fission,
χ_f = fission spectrum (normalized to 1.0),
χ_s = external/intrinsic source spectrum (normalized to 1.0),
$s = s(\boldsymbol{r}, \Omega)$ = source distribution per unit volume per unit angle, and
$\chi_s s = \chi_s(E)\, s(\boldsymbol{r}, \Omega)$ = energy-dependent source distribution.

The product, $g^* S$, is defined as the *equivalent fundamental-mode source*, which has many applications in reactor physics, particularly in reactor-kinetic theory, criticality safety, reactor-noise theory, and reactor start-up operations.

Although Eq. (4) can be used to evaluate the equivalent fundamental-mode source for a given source distribution, one would also like to be able to measure this quantity. This measurement can be accomplished by recording the count rate of a core detector as a function of subcritical reactivity with and without a calibrated point source at some known location within the system. Based on the ratio of the slopes of the least-squares fit of these two sets of data and a calculation of g^* for the point source in the known location, the equivalent fundamental-mode source for the normally-existing external/intrinsic source distribution can be calculated from

$$g_i^* S_i = \frac{g_p^* S_p}{\left(\frac{m_{pi}}{m_i} - 1\right)} \quad , \qquad (5)$$

where m_i is the slope of the detector count rate without the calibrated point source in the system, m_{pi} is the slope of the detector count rate with the calibrated point source in the system, g_p^* is the g^*-factor corresponding to the location where the calibrated point source, S_p, was placed during the measurement.

This experimental procedure was performed on the zero-power XIX-1 assembly located at the Fast Critical Assembly (FCA) facility operated by the Japan Atomic Energy Research Institute (JAERI).[2] The XIX-1 assembly is a multiregion system comprised of an inner core fueled with highly enriched ^{235}U metal. The core is surrounded by an inner blanket (referred to as the 'soft blanket') containing a significant amount of depleted uranium-oxide and sodium, and an outer blanket (referred to as the 'depleted blanket') containing only depleted uranium metal. Our goal in this experiment was to measure the equivalent fundamental-mode source for the intrinsic source produced primarily by the spontaneous fissioning of the ^{238}U in the soft and depleted blankets. The total neutron yield from the ^{238}U was estimated to be approximately 343,000 n/s. In this measurement, a calibrated ^{252}Cf source of strength 97,600 ± 1% n/s was placed in the center of the assembly where g_p^* was calculated to be 1.68 using the original 16-group Hansen-Roach cross section set.[3-4] A plot of the detector count rate as a function of inverse reactivity is shown in Fig. 1. From these data, the equivalent fundamental-mode source for the intrinsic source, $g_i^* S_i$, was determined to be 20,600 ± 3% n/s. The overall g^*-factor for the intrinsic source distribution corresponds to 6%, which agrees reasonably well with theoretical predictions of 4.2%.

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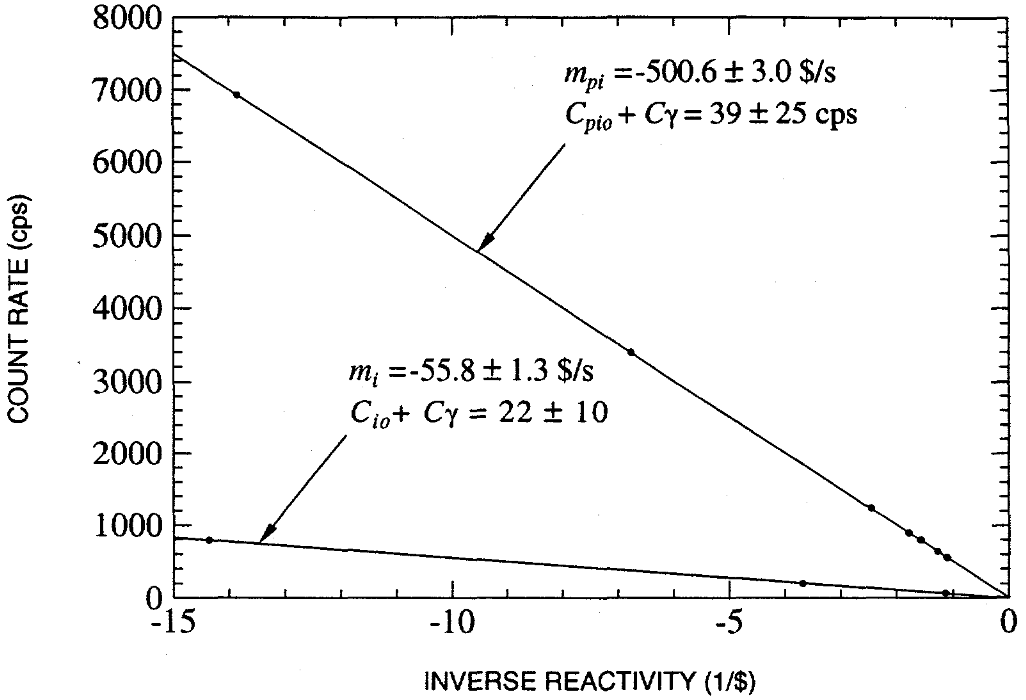

Fig. 1. Plot of the count rate of the four detectors summed together vs. inverse reactivity.